Renewable Energy Sources- An Application Guide

Energy for Future

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Abstract

This article presents a review about the application of various non-conventional & renewable energy sources especially solar energy. Renewable energy sources are indigenous, and can therefore contribute to reducing dependency on energy imports and increasing security of supply. Development of renewable energy sources can actively contribute to job creation, predominantly among the small and medium sized enterprises which are so central to the community economic fabric, and indeed themselves form the majority in the various renewable energy sectors. Deployment of renewables can be a key feature in regional development with the aim of achieving greater social and economic cohesion within the community. Finally, this paper explores six broad types of renewable energy sources, their characteristics and typical application: solar energy, wind energy, bio energy, hydro energy, geothermal energy, wave and tidal energy.

Keywords

Renewable Energy; Solar Energy; Wind Energy; Bio-Energy; Hydro Energy; Geothermal Energy; Wave and tidal Energy

Introduction

Energy is the primary force in the universe. Energy defines the Earth's biomes and sustains life. All life, from single-celled microbes to blue whales, exists in a continuous process of consuming, using, and storing energy. Human communities work in the same way as other communities with regard to energy management. Any community consumes fuel to produce energy, but the community must also conserve some of the fuel for the next generation. This conservation of energy sources from one generation to the next is the principle behind sustainability, the process by which a system survives for a period of time. No system in biology lasts forever, and this is also true for sustainability. Sustainability prolongs the time that living things can survive, but it cannot ensure that life will go on forever.

Living sustainably means conserving nonrenewable resources by intelligent use of renewable resources. Even renewable resources must be managed carefully or else they too can disappear faster than they are replaced. The world is now experiencing this very problem because in many places forests, plants, wild animals, clean water, clean air, and rich soil have become depleted before nature can replace them. Sustainable use of resources depends on the principles of conservation and resource management. Since the 1960s, some people have known that conservation of nonrenewable energy sources is of paramount importance. At the same time, people must put increased effort into using renewable energy sources from the sun, wind, and water.

The concept of renewable versus nonrenewable resources provides the cornerstone of sustainability. Renewable resources are replaced by natural processes over time, but even these must be conserved so that they are not used up faster than nature can replace them. Conversely, nonrenewable resources such as oil or minerals are formed in the earth over millions of years. Earth can replenish nonrenewable resources, but this occurs over eons such as the millions of years needed to transform organic matter into fossil fuels. Do people have any real chance to affect the entire planet and preserve its natural wealth? Environmentalists think everyone can indeed make a difference in building sustainability by following the three rs—reduce, reuse, and recycle.

Energy companies would be wise not to deplete resources faster than the earth replaces them, a process known as recharging. However, replenishment of renewable resources has become increasingly difficult because of a growing world population. Although many factors contribute to population growth at unsustainable rates, two important historical developments may have had the largest impact on

population because they increase life span. First, the development of the microscope 275 years ago led to greater knowledge of microbes and an increasing understanding of disease. Second, conveniences introduced by the industrial revolution alleviated the need for manual labor in many industries. In short, life had become less physically demanding, and medicine had reduced the infant mortality rate and lengthened life spans. Populations in developed and developing regions began to undergo exponential growth, which means that the numbers of humans increase at an increasingly faster pace over a short period of time. Exponential population growth is the single most significant factor in humans' increasing ecological footprint. In this decade, humans have been depleting resources 21 percent faster than earth can recharge them. Environmental scientists often describe this problem as the number of planet earths that people need to support their activities. At present, humans need 1.21 earths to support current consumption of resources.

Renewable energy sources are fundamentally different from fossil fuel or nuclear power plants because of their widespread occurrence and abundance. The primary advantage of many renewable energy sources are their lack of greenhouse gas and other emissions in comparison with fossil fuel combustion. Most of the renewable energy sources do not emit any additional carbon dioxide and do not introduce any risk such as nuclear waste. A renewable energy system converts the energy found in sunlight, wind, falling-water, sea-waves, geothermal heat, or biomass into a form, we can use such as heat or electricity. Most of the renewable energy comes either directly or indirectly from sun and wind and can never be exhausted, and therefore they are called renewable. However, most of the world's energy sources are derived from conventional sources-fossil fuels such as coal, oil, and natural gases. These fuels are often termed non-renewable energy sources. Although, the available quantity of these fuels are extremely large, they are nevertheless finite and so will in principle 'run out' at some time in the future.

Renewable energy sources are essentially flows of energy, whereas the fossil and nuclear fuels are, in essence, stocks of energy.

Various forms of renewable energy sources:

Solar energy

Wind energy

Bio energy

Hydro energy

Geothermal energy

Wave and tidal energy

This paper focuses on various applications of renewable energy sources such as solar, wind, bio and hydro energy.

Solar Energy

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m (Fig. 1). The sun is about 1.5×10^8 km away from earth, so, because thermal radiation travels with the speed of light in a vacuum (300,000 km/s), after leaving the sun solar energy reaches our planet in 8 min and 20s. As observed from the earth, the sun disk forms an angle of 32 min of a degree.

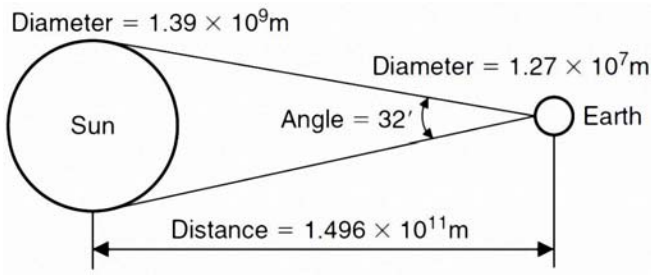

FIG. 1 EARTH–SUN GEOMETRIC RELATIONSHIPS

This is important in many applications, especially in concentrator optics, where the sun cannot be considered as a point source and even this small angle is significant in the analysis of the optical behavior of the collector. The sun has an effective black-body temperature of 5760K. The temperature in the central region is much higher. In effect, the sun is a continuous fusion reactor in which hydrogen is turned into helium. The sun's total energy output is 3.8×10^{20} MW, which is equal to 63 MW/m^2 of the sun's surface. This energy radiates outward in all directions. The earth receives only a tiny fraction of the total radiation emitted, equal to 1.7×10^{14} kW; however, even with this small fraction, it is estimated that 84 min of solar radiation falling on earth is equal to the world energy demand for one year (about 900 EJ). As seen from the earth, the sun rotates around its axis about once every four weeks. Solar energy is the most readily available and free source of energy since prehistoric times. It is estimated that solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year. India receives solar energy in the region of 5 to 7 kWh/m^2 for

300 to 330 days in a year. This energy is sufficient to set up 20 MW solar power plant per square kilometre land area.

Solar energy can be utilized through two different routes, as solar thermal route and solar electric (solar photovoltaic) routes. Solar thermal route uses the sun's heat to produce hot water or air, cook food, drying materials etc. Solar photovoltaic uses sun’s heat to produce electricity for lighting home and building, running motors, pumps, electric appliances, and lighting. Solar energy can meet three distinct applications: heating water, heating air, and generation of electricity in any residential or commercial setting. In most cases, solar energy provides the lowest lifecycle cost, and the lowest environmental impact from the release of greenhouse gases (GHG).

Water Heating

An obvious use of solar energy is for heating air and water. Dwellings in cold climates need heated air for comfort, and in all countries hot water is used for washing and other domestic purposes. Domestic water heating systems typically use collectors that have much lower losses at higher water temperatures. These are either flat-plate, evacuated flat-plate or evacuated tube collectors and are integrated with collector storage systems (Fig. 2 and Fig. 3).

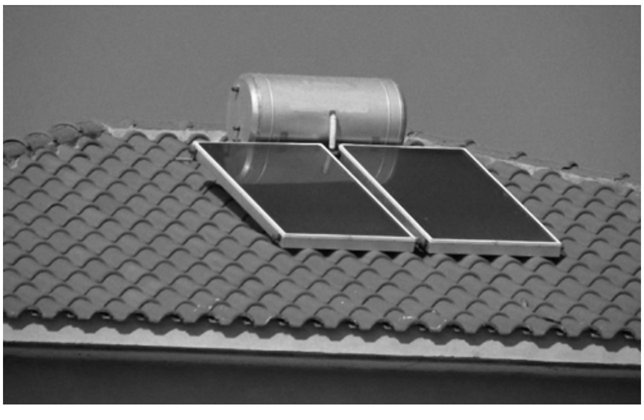

FIG. 2 FLAT-PLATE COLLECTOR CONFIGURATION

A very simple system for solar water heating can be made of a black water filled tank that is exposed to sunlight in summer. If the tank is installed higher than the tap, the warm water can be used without any further component. An example for such an application is a solar shower that is sold as camping equipment. In principle, it is a black sack hung on a high branch of a tree. If this sack is exposed for some hours to solar radiation, a shower with solar heated water can be taken.

FIG. 3 EVACUATED TUBE COLLECTOR CONFIGURATION

However, this system does not meet the demand of daily routine. After the sack is empty it must be refilled again by hand. To avoid this inconvenience, sack and tap can be pressure-sealed and a hose can then be connected to replace water automatically. As a further improvement a solar collector with a high efficiency all year round can replace the sack. However, the collector content is only sufficient for a very short shower and the water temperatures will be very high. Therefore, a storage tank is needed. Two systems to integrate hot water storage tanks into solar energy systems are described in the following sections.

1) Thermosyphon Systems

A thermosyphon system as shown in Fig. 4 makes use of gravity.

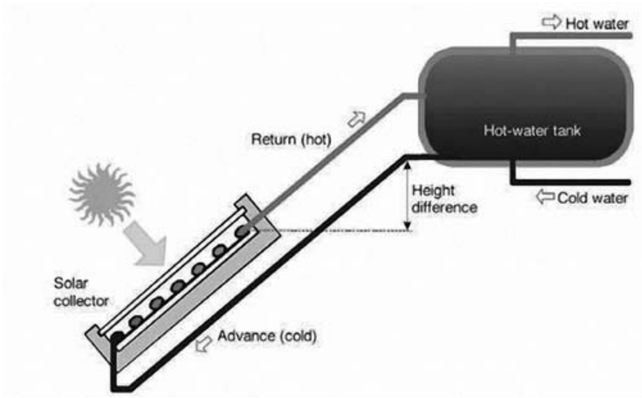

FIG. 4 SCHEMATIC OF A THERMOSYPHON SYSTEM

Cold water has a higher specific density than warm water. It is therefore heavier and sinks to the bottom. The collector is always mounted below the water storage tank. Cold water from the bottom of the storage tank flows to the solar collector through a descending water pipe. When the collector heats up the water, the water rises again and flows back to the tank through an ascending water pipe at the upper end of the collector. The cycle of tank, water

pipes and collector heats up the water until temperature equilibrium is reached. The consumer can draw off hot water from the top of the tank. Used water is replaced through a fresh supply of cold water through an inlet at the bottom of the tank. This cold water joins the cycle and is heated in the collector in the same way as before. Due to higher water temperature differences at higher solar irradiances, the warm water rises faster than at lower irradiances and the flow rates are increased. Therefore, the water circulation adapts itself nearly perfectly to the available solar irradiance.

2) *Systems with Forced Circulation*

In contrast to thermosyphon systems, systems with forced circulation use an electrical pump to move the water in the solar cycle. The collector and storage tank can be installed independently and a height difference between the tank and collector is no longer necessary. However, the pipe lengths should be designed to be as short as possible since all warm water pipes cause heat losses. Fig. 5 shows a system with forced circulation.

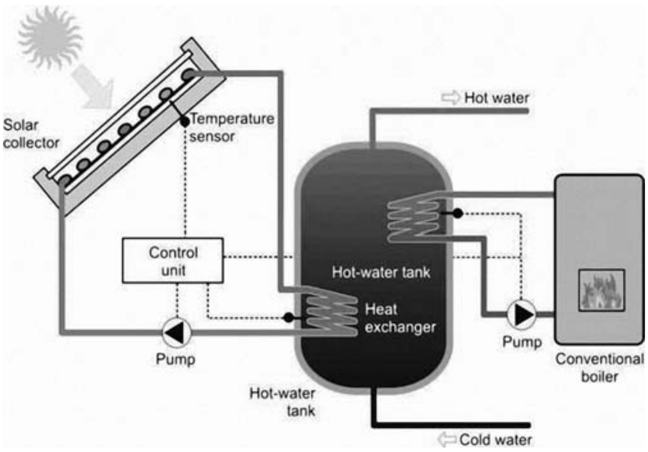

FIG. 5 SCHEMATIC OF A SYSTEM WITH FORCED CIRCULATION

A few industrial application of solar water heaters are listed below:

- Hotels: Bathing, kitchen, washing, laundry applications
- Dairies: Ghee (clarified butter) production, cleaning and sterilizing, pasteurization
- Textiles: Bleaching, boiling, printing, dyeing, curing, ageing and finishing
- Breweries & Distilleries: Bottle washing, wort preparation, boiler feed heating
- Chemical /Bulk drugs units: Fermentation of mixes, boiler feed applications
- Electroplating/galvanizing units: Heating of plating baths, cleaning, degreasing applications
- Pulp and paper industries: Boiler feed applications, soaking of pulp.

Space Heating

Space heating is of particular relevance in colder countries where a significant amount of energy is required for this purpose. In India it is of important mainly in the Northern and Northern-Eastern regions in winter.

1) *Active Methods*

An active method one which utilizes a pump or a blower to circulate the fluids involved in the space heating system. One system is illustrated in Fig. 6. In this system, water is heated in solar flat plate collectors (A) and stored in the tank (B). Energy is transferred to the air circulating in the space to be heated by means of the water to air heat exchanger (E). Two pumps (C) provide forced circulation between the collectors and the tank, and between the tank and the heat exchanger. Provision is also made for adding auxiliary heat (D). Since the solar energy is first being used to heat water, the system shown in Fig. 6 can be easily modified to be a two-in-one system supplying hot water as well as hot air for space heating.

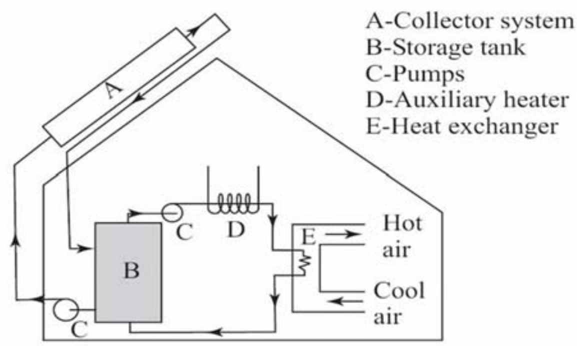

FIG. 6 SCHEMATIC DIAGRAM OF A SPACE HEATING SYSTEM USING LIQUID FLAT-PLATE COLLECTOR

An alternative approach to space heating is to heat air directly in solar air heaters (A), as shown in Fig. 7. The heat is then stored in porous bed storage (B) packed with rock, gravel or pebbles. Energy is extracted ant transferred to the space to be heated by blowing cool air through the porous bed. Once again an auxiliary heater (D) is provided for supplying make-up-heat.

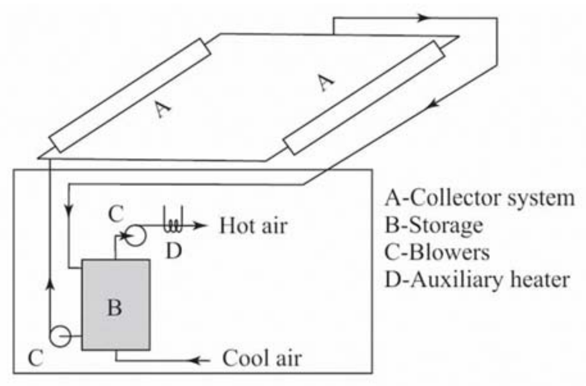

FIG. 7 SCHEMATIC DIAGRAM OF A SPACE HEATING SYSTEM USING SOLAR AIR HEATERS

2) *Passive Methods*

A passive method is one in which thermal energy flows through a living space by natural means without the help of a mechanical device like a pump or a blower. A schematic diagram of a passive space-heating system designed by Professor Trombe is shown in Fig. 8.

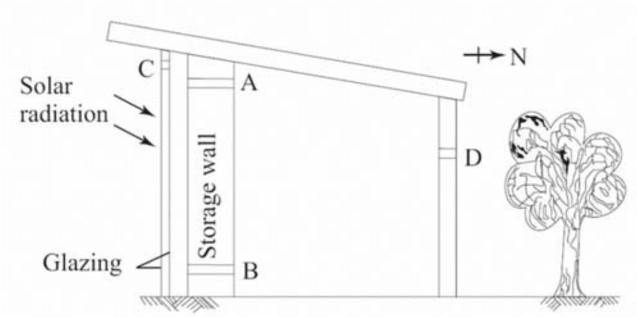

FIG. 8 SPACE HEATING BY PASSIVE METHODS-THE TROMBE WALL

The south face of the house to be heated is provided with a single or double glazing. Behind it is a thick "black", concrete wall, which absorbs the sun's radiation and serves as a thermal storage. Vents (A and B), which can be kept open or closed, are provided near the top and bottom of the storage wall. The whole unit consisting of the storage wall with vents and the glazing is referred to as a Trombe wall.

During the day, both vents A and B are kept open. The air between the inner glazing and the wall gets heated and flows into the living space through the top vent. Simultaneously, the cooler air from the room is pulled out of the living space through the bottom vent. Thus, a natural circulation path is set up. Some energy transfer to the living space also takes place by convection and radiation from the inner surface of the storage wall. During the night, both vents are closed and energy transfer takes place only by convection and radiation from the inner surface.

Another passive design approach for space heating is to construct a sunspace or greenhouse next to living space to be heated. The sunspace is located on the south side of the building. It has a large glass roof and there is a thick wall with vents at the top and bottom linking it with the living space (Fig. 9). Thus the sunspace acts as a buffer zone between the living space and the outdoor conditions. During the day, sun space get heated up and warm air enters the living space through the top opening A. Cooler air from the living space is pulled out through the bottom opening B thereby establishing a natural circulation flow. In addition, energy is stored in the link wall. During the night, the openings are closed and the energy stored in the link wall is conducted through it and transferred to the living space by convection and radiation from the inner surface.

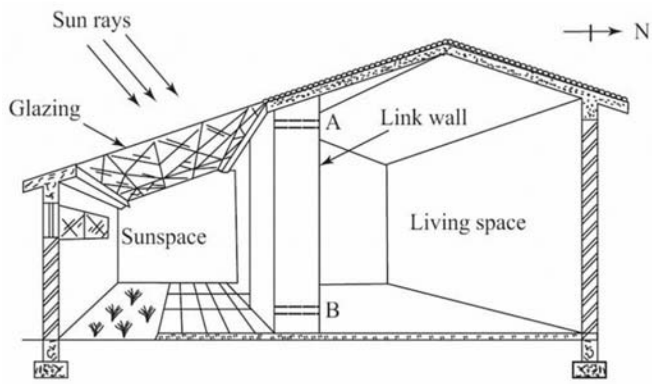

FIG. 9 SCHEMATIC DIAGRAM OF A SUNSPACE FOR PASSIVE SPACE HEATING

Space Cooling and Refrigeration

One of the interesting thermal applications of solar energy is for the purpose of cooling. Space cooling may be done with the objective of providing comfortable living conditions (air-conditioning) or of keeping a food product cold (refrigeration). Since the energy of the sun is being received as heat, the obvious choice is a system working on the absorption refrigeration cycle which requires most of its energy input as heat. Cooling is required most in summer. Hence, in this case, there is a seasonal matching between the energy needs of the space cooling system and the availability of solar radiation.

A diagram of a simple solar operated absorption system is shown in Fig. 10.

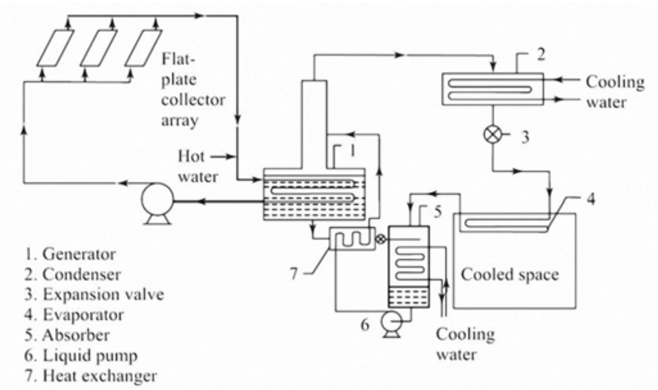

FIG. 10 SOLAR ABSORPTION REFRIGERATION SYSTEM

Water heated in a flat-plate collector array is passed through a heat exchanger called the generator, where it transfers heat to a solution mixture of the absorbent and refrigerant, which is rich in the refrigerant. Refrigerant vapour is boiled off at a high pressure and goes to the condenser where it is condensed into a high pressure liquid. The high pressure liquid is throttled to a low pressure and temperature in an expansion valve, and passes through the evaporator coil. Here, the refrigerant vapour absorbs heat and cooling is therefore obtained in the space surrounding this coil. The refrigerant vapour is now absorbed into a solution mixture withdrawn from the generator, which is weak in refrigerant concentration. This yields a rich solution which is pumped back to the generator, thereby completing the cycle. The rich solution flowing from the absorber to the generator is usually heated in a heat exchanger by the weak solution withdrawn from the generator. This helps to improve the performance of the cycle. Some of the common refrigerant-absorbent combinations used are ammonia-water and water-lithium bromide, the latter being used essentially for air-conditioning purposes. Typical values for the coefficient of performance (the ratio of the refrigerating effect to the heat supplied in the generator) range between 0.5 and 0.8.Unfortunately, the installation cost of a solar absorption refrigeration system is high because of the cost of the large collector array required. Thus commercialization has not taken place although a few demonstration units have been set up.

Power Generation

The generation of electrical power is one of the most important applications of solar energy source. There are two methods for generation of electrical power.

1) Solar Thermal Power Generation

Solar thermal power cycles can be classified as low, medium and high temperature cycles. Low temperature cycles work at maximum temperatures of about 100°C, medium temperature cycles work at maximum temperatures up to 400°C, while high temperature cycles work at temperatures above 400°C. Low temperature systems use flat-plate collectors or solar ponds for collecting solar energy. Systems working on the solar chimney concept have also been suggested. Medium temperature systems use the line-focussing parabolic collector technology. High temperature systems use either paraboloid dish collectors or central receivers located at the top of towers.

Low Temperature Systems: A diagram of a typical low temperature system using flat-plate collectors and working on a Rankine cycle is shown in Fig. 11.

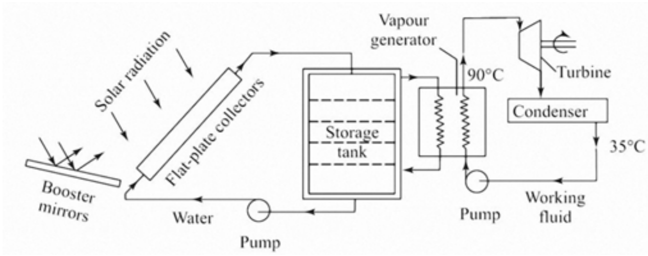

FIG. 11 LOW TEMPERATURE POWER GENERATION CYCLE USING FLAT-PLATE COLLECTORS

The energy of the sun is collected by water flowing through the array of flat-plate collectors. In order to get the maximum possible temperature, booster mirrors which reflect radiation on to the flat-plate collectors are sometimes used. The hot water at temperatures close to 100°C is stored in a well-insulated thermal storage tank. From here, it flows through a vapour generator through which the working fluid of the Rankine cycle is also passed. The working fluid has a low boiling point. Consequently, vapour at about 90°C and a pressure of a few atmospheres leaves the vapour generator. This vapour then executes a regular Rankine cycle by flowing through a prime mover, a condenser and a liquid pump. The working fluids normally used are organic fluids like methyl chloride and toluene, and refrigerants like R-11, R-113 and R-114. It has to be noted that the overall efficiency of this system is rather low, because the temperature difference between the vapour leaving the generator and the condensed liquid leaving the condenser is small. For the cycle shown in Fig. 11, the temperature difference is only 55°C. This leads to a Rankine cycle efficiency of 7 to 8 per cent. The

efficiency of the collector system is of the order of 25 per cent. Hence an overall efficiency of only about 2 per cent is obtained. The concept of a solar chimney power plant was suggested in the 1970s. It is also called a solar updraft tower power plant. In such a plant, a tall central chimney is surrounded at its base by a circular greenhouse consisting of a transparent cover supported a few metres above the ground by a metal frame (Fig. 12).

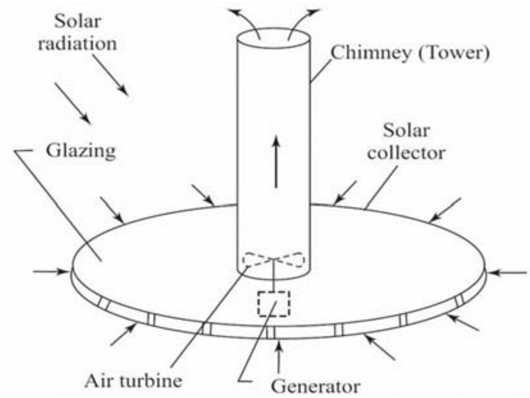

FIG. 12 SOLAR CHIMNEY POWER PLANT

Sunlight passing through the transparent cover causes the air trapped in the greenhouse to heat up by 10° to 20°C. Thereby a convection system is set up in which the hot air is drawn up through the central chimney, and is continuously replenished by fresh air drawn in at the periphery of the greenhouse. The energy contained in the updraft air is converted into mechanical energy by turbines located at the base of the chimney and then into electrical energy by conventional electrical generators.

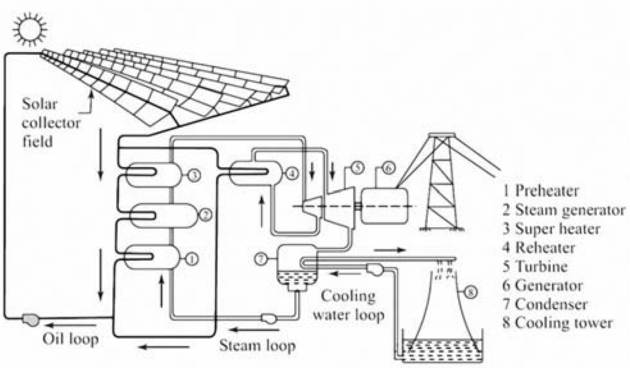

FIG. 13 MEDIUM TEMPERATURE POWER GENERATION CYCLE USING CYLINDRICAL PARABOLIC CONCENTRATING COLLECTORS

Medium Temperature Systems: Among solar thermal-electric power plants, those operating on medium temperature cycles and using the line-focussing parabolic collector technology at a temperature close to 400°C have proved to be the most cost effective and successful so far. A schematic diagram of a typical plant is shown in Fig. 13.

High Temperature Systems: Two concepts have been experimented with in the case of high temperature systems. These are the paraboloid dish concept and the central receiver concept. In the paraboloid dish concept, the concentrator tracks the sun by rotating about two axes and the sun's rays are brought to a point focus. A fluid flowing through a receiver at the focus is heated and this heat is used to drive a prime mover. Typically, Stirling engines have been favoured as the prime movers. For this reason, such systems are referred to as Dish-Stirling Systems. Because of the limitations on the size of the concentrator, paraboloid dish systems can be expected to generate power in kilowatts rather than megawatts. Thus they can be expected to meet the local power needs of communities, particularly in rural areas.

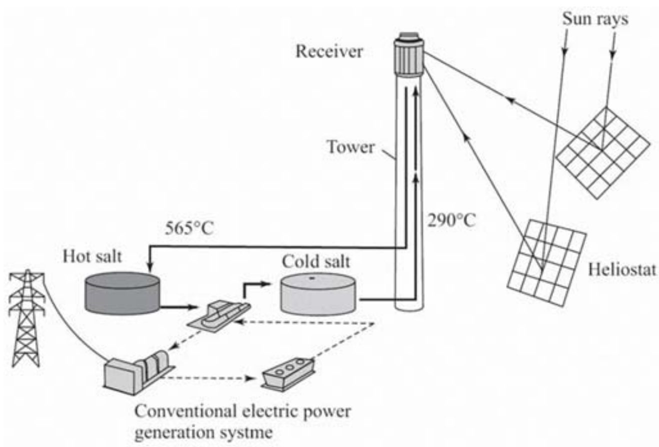

FIG. 14 SCHEMATIC DIAGRAM OF A TYPICAL CENTRAL RECEIVER SYSTEM USING A MOLTEN SALT AS THE HEAT TRANSFER FLUID

In a central receiver system, solar radiation reflected from an array of large mirrors is concentrated on a receiver situated at the top of a supporting tower. The mirrors are called heliostats and they are placed on the ground around the tower. Their orientation is individually controlled so that throughout the day they reflect beam radiation on the receiver. A fluid flowing through the receiver absorbs the concentrated radiation and transports the heat to the ground level where it is used to operate a thermodynamic cycle like the Rankine or the Brayton cycle. Molten salts, water (converted to steam) and air have been used as the heat transfer fluids. Because of the use of a receiver

placed at the top of a tower, a central receiver system is also referred to as a power tower. A schematic diagram of a typical central receiver system using a molten salt as the heat transfer fluid is shown in Fig. 14. The molten salt used frequently is a mixture of 60 per cent sodium nitrate and 40 per cent potassium nitrate.

Cold salt at 290°C is pumped from a tank at ground level to the receiver at the top of a tower where it is heated by the concentrated radiation to a temperature of 565°C. The salt flows back to another tank at ground level. In order to generate electricity, hot salt is pumped from the hot tank through a steam generator where superheated steam is produced. The superheated steam then goes through a Rankine cycle to produce mechanical work and then electricity. The heliostat array can be sized to collect more power than is required by the electricity generation system. In that case, the excess thermal energy in the form of excess salt at 565°C accumulates in the hot tank and serves as a thermal storage.

2) *Photovoltaic Conversion*

Electricity can be produced from sunlight through a process called the PV effect, where "photo" refers to light and "voltaic" to voltage. The term describes a process that produces direct electrical current from the radiant energy of the Sun. The PV effect can take place in solid, liquid, or gaseous material; however, it is in solids, especially semiconductor materials, that acceptable conversion efficiencies have been found. Solar cells are made from a variety of semiconductor materials and coated with special additives. The most widely used material for the various types of fabrication is crystalline silicon, representing over 90% of global commercial PV module production in its various forms.

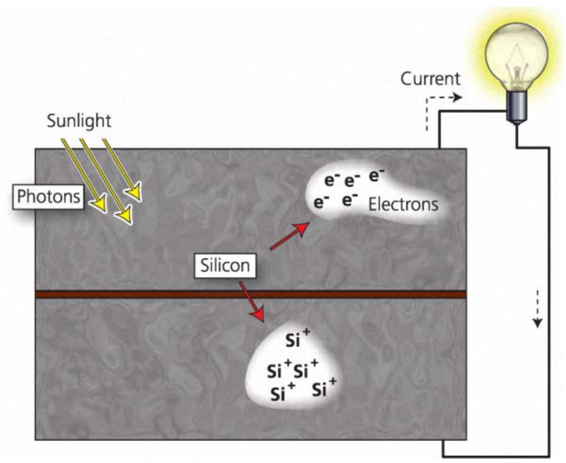

FIG. 15 A PHOTOVOLTAIC CELL

A photovoltaic cell used in capturing solar energy receives photons (the sun's rays), which silicon absorbs. This action releases an electron from a silicon atom each time a photon strikes. Oppositely charged poles on either side of the cell induce the electrons to form a current. Fig. 15 shows a photovoltaic cell.

A typical silicon cell, with a diameter of 4 in., can produce more than 1 W of direct current (DC) electrical power in full sun. Individual solar cells can be connected in series and parallel to obtain desired voltages and currents. These groups of cells are packaged into standard modules that protect the cells from the environment while providing useful voltages and currents. PV modules are extremely reliable because they are solid state and have no moving parts. Silicon PV cells manufactured today can provide over 40 years of useful service life. PV devices—or solar cells—are made from semiconductor materials. Semiconductor materials are those elements or compounds that have conductivity intermediate to that of metals or insulators.

In spite of the high initial cost, photovoltaic systems are being used increasingly to supply electricity for many applications requiring small amounts of power. Their cost-effectiveness increases with the distance of the location (where they are to be installed) from the main power grid lines. For example, studies in India show that it is more economical to install a stand-alone PV system instead of a transmission line to a village having a load of 10 kW, if the village is more than 40 km from the grid line.

Some applications for which PY systems have been developed are,

- Pumping water for irrigation and drinking,
- Electrification for remote villages for providing street lighting, home lighting and other community services,
- Telecommunication for the post and telegraph and railway communication network,

In addition, solar cells are being used extensively in consumer product appliances where very small amounts of power are needed. These cells are generally amorphous silicon cells.

A diagram of a typical system for pumping water from a bore well is shown in Fig. 16. Such systems have been designed to pump water from depths of

20 to 100 metres and to supply 5000 to 50000 litres per day.

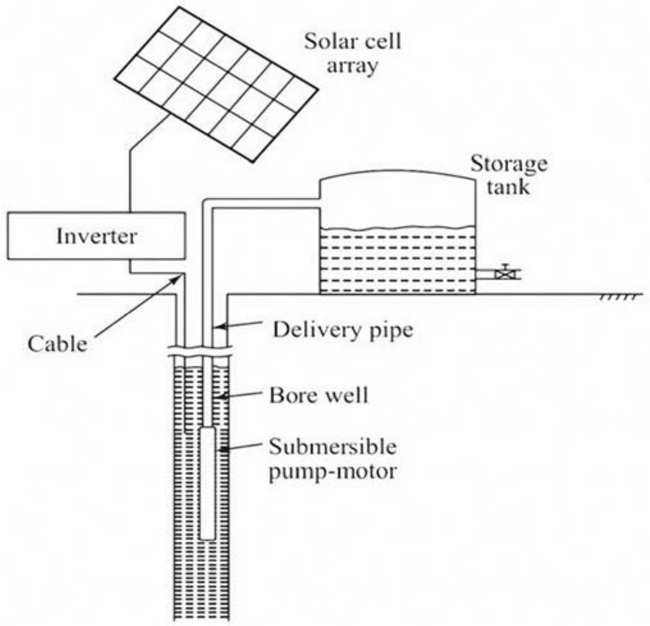

FIG. 16 A PHOTOVOLTAIC WATER-PUMPING SYSTEM

As seen in Fig. 16 a solar cell array supplies power through a dc-ac inverter to an electric motor coupled to a submersible pump. The pump is installed below the water level of the bore well. Its discharge is connected through a delivery pipe to storage at ground level. Water can be withdrawn from the storage tank for use when required. Usually systems for pumping water do not have storage batteries and work only during the day when adequate solar radiation is available. However other PV systems which have to supply power during the evening or night require storage batteries to store the electrical energy generated during the day. The capacity of the battery is determined by the nature of the application. For example, in a street lighting system, the capacity of the storage battery would be such that the street lights would be on for five or six hours every night.

Solar Distillation

In many small communities, the natural supply of fresh water is inadequate in comparison to the availability of brackish or saline water. Solar distillation can prove to be an effective way of supplying drinking water to such communities. The principle of solar distillation is simple and can be explained with reference to Fig. 17, in which a conventional basin-type solar still is shown. The still consists of a shallow air-tight basin lined with a black, impervious material which contains the saline water.

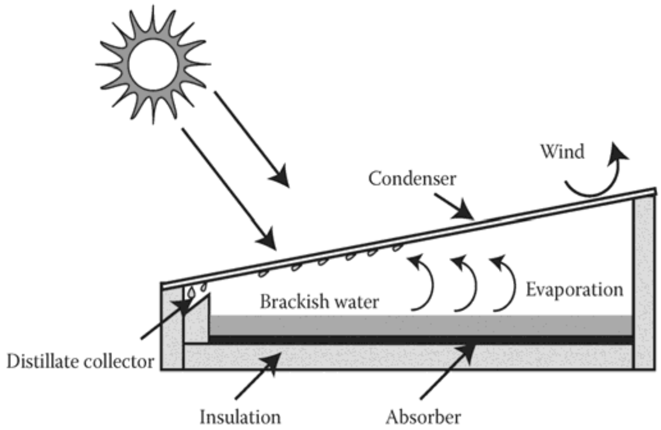

FIG. 17 SOLAR STILL

A sloping transparent cover is provided at the top-Solar radiation is transmitted through the cover and is absorbed in the black lining. It thus heats up the water by about 10° to 20°C and causes it to evaporate. The resulting vapour rises, condenses as pure water on the underside of the cover and flows into condensate collection channels on the sides. An output of about 3 liters/m2 with an associated efficiency of 30 to 35 per cent can be obtained in a well-designed still on a good sunny day. A number of basin-type solar-still plants having areas greater than 100 m^2 are in operation in many parts of Africa and the West Indies.

Solar Drying

One of the traditional uses of solar energy has been for drying of agricultural products. The drying process removes moisture and helps in the preservation of the product. Traditionally, drying is done on open ground. The disadvantages associated with this are that the process is slow and that insects and dust get mixed with the product. The uses of dryers help to eliminate these disadvantages. Drying can then be done faster and in a controlled fashion. In addition, a better-quality product is obtained. A cabinet-type solar dryer, suitable for small-scale use, is shown in Fig. 18.

The dryer consists of an enclosure with a transparent cover. The material to be dried is placed on perforated trays.

Solar radiation entering the enclosure is absorbed in the product itself and the surrounding internal surfaces of the enclosure. As a result, moisture is removed from the product and the air inside is heated. Suitable openings at the bottom and top ensure a natural circulation. Temperatures ranging from 50°C to 80°C are usually attained and the drying time ranges from 2 to 4 days. Typical products which can

be dried in such devices are dates, apricots, chillies, grapes etc.

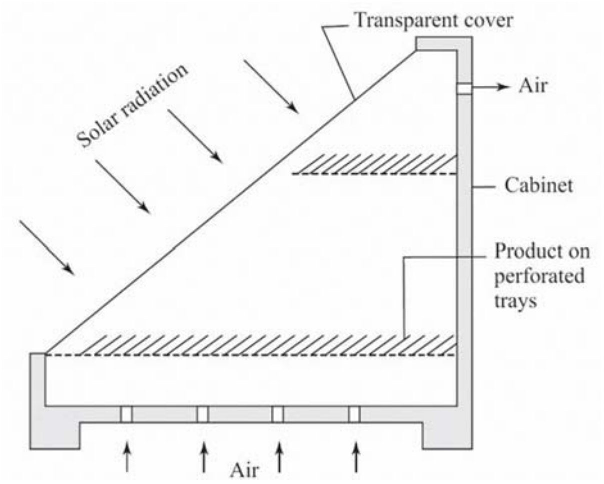

FIG. 18 A CABINET-TYPE SOLAR DRYER

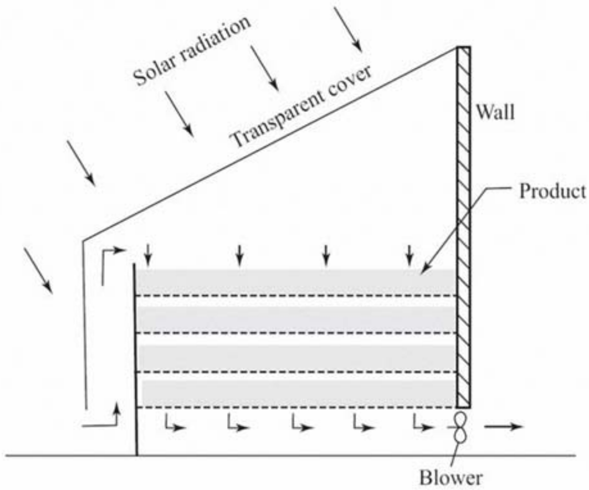

FIG. 19 FORCED CIRCULATION DRYER (DIRECT GAIN)

For large-scale drying, the passive device of Fig. 18 relying on natural circulation is replaced by an active device with forced circulation as shown in Fig. 19. Systems of this type have been used for drying timber.

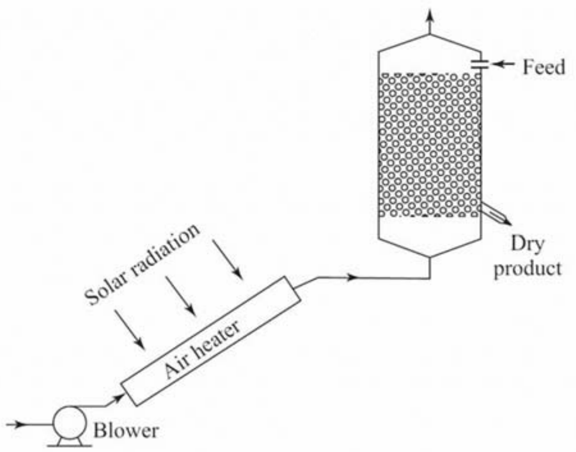

FIG. 20 FORCED CIRCULATION DRYER (INDIRECT GAIN)

An indirect type of active device is used when the solar radiation falling directly on the product (as in Figs. 18 and 19) is not adequate, or the temperature of the product needs to be controlled. One such system is shown in Fig. 20. Here, the air is heated separately in an array of solar air heaters and then ducted to the chamber in which the product to be dried is stored. Such dryers are suitable for food grains, tea, spices, etc. and for products like leather and ceramics.

Solar Cooking

An important domestic thermal application is that of cooking. Over the past 40 years, a number of designs of solar cookers have been developed, a few of which are described here. Solar cooker designs generally fall into one of two categories. One category is the box-type cooker, a slow cooking device suitable for domestic purposes. It essentially consists of a rectangular enclosure insulated on the bottom and sides, and having one or two glass covers on the top. Solar radiation enters through the top and heats up the enclosure in which the food to be cooked is placed in shallow vessels. A typical size available has an enclosure about 50 cm square and 12 cm deep. Temperatures around 100°C can be obtained in these cookers on sunny days and pulses, rice, vegetables, etc., can be readily cooked. The time taken for cooking depends upon the solar radiation and varies from half an hour to two and a half hours.

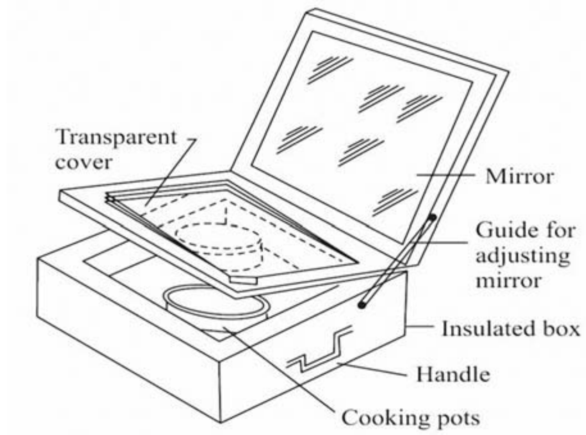

FIG. 21 BOX-TYPE COOKER WITH ONE REFLECTOR

A single glass reflector whose inclination can be varied is usually attached to the box-type cooker. A sketch of such a cooker is shown in Fig. 21. The addition of the mirror helps in achieving enclosure temperatures which are higher by about 15° to 20°C. As a result, the cooking time is reduced. Cookers with reflectors on all four edges have also been built. Box-type cookers with no reflector or with one reflector are simple to use and

require little attention. As a result, they have found the maximum acceptance amongst all the designs developed. The item to be cooked has only to be placed inside and taken out, so that with some experience, the operator does not have to spend much time in the sun. However, the disadvantage is that they cannot be used for cooking items like chapatis and purees since these require higher temperatures.

The second categories of solar cookers developed are those in which the radiation is concentrated by a paraboloid reflecting surface. The cooking vessel is placed at the focus of the paraboloid mirror and is thus directly heated. This cooker is referred to as a dish solar cooker. Temperatures well above 200°C are obtained in it and it can be used for cooking food items requiring roasting, frying or boiling. The disadvantage of a dish cooker is that it requires manual tracking every 15 or 20 minutes. Also, since the cooking is done outdoors, the operator has to spend a considerable amount of time in the sun. A variation of the paraboloid-type cooker has been developed by Scheffier such that solar radiation can be concentrated and brought inside the kitchen. The reflector is a small lateral section of a much larger paraboloid. The inclined cut produces the typical shape of the Scheffier reflector. The reflector usually consists of a number of mirror facets supported by a steel frame. It is mounted outside the kitchen facing south (in the northern hemisphere). It reflects the solar rays through an opening in the north wall of the kitchen on to a secondary reflector inside the kitchen. The secondary reflector further concentrates the rays on to the bottom of the cooking vessel (Fig. 22).

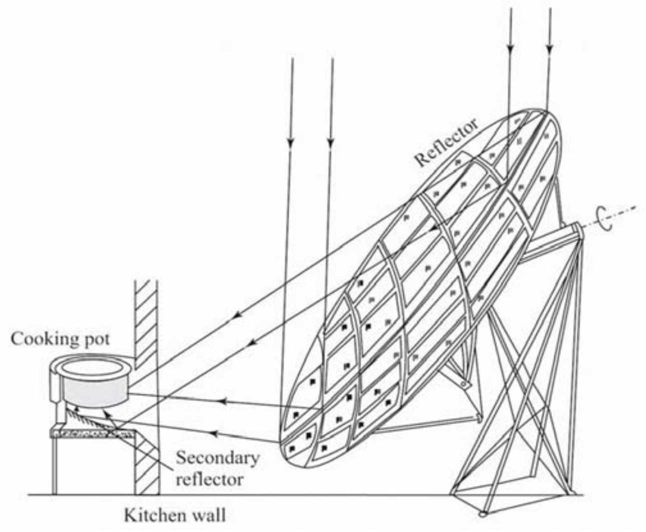

FIG. 22 SCHEMATIC DIAGRAM OF A SCHEFFIER COOKER

These cookers require tracking such that the focus stays fixed. The daily rotation is generally carried out by a mechanical tracking device (clock work). In addition, every second or third day, the tilt of the reflector is adjusted and the reflector is flexed so that most of the solar rays are reflected to the secondary reflector. Temperatures as high as 400°C can be attained and all types of cooking/frying are possible. One need not have to go outside in the sun unlike a normal paraboloid cooker. Cooking for about 40 to 50 persons is possible with this cooker.

Solar Cars

A solar car is an electric vehicle powered by energy obtained from solar panels on the surface of the car which convert the sun's energy directly into electrical energy. Solar cars are not currently a practical form of transportation. Although they can operate for limited distances without sun, the solar cells are generally very fragile. Development teams have focused their efforts on optimizing the efficiency of the vehicle, but many have only enough room for one or two people. Although we won't find solar cars at any dealerships, people have been building their own models since the 1970s. Ed Passerini who constructed his own completely solar powered car called the "Bluebird" in 1977 and Larry Perkins who drove the "Quiet Achiever" in 1982 both receive nods as the first people to do so. Ford and Mazda have even tested the waters with solar hybrid concept cars. The 2006 Ford Reflex installed solar panels in the headlights, and the 2005 Mazda Senku featured solar panels on its roof to help charge its battery. The 2008 Cadillac Provoq uses solar panels to power accessories, such as interior lights and the audio system. Fig. 23 shows a solar car.

FIG. 23 A SOLAR CAR

Solar Power Satellite

A solar power satellite (SPS) is a proposed satellite built in high earth orbit that uses microwave power transmission to beam solar power to a very large antenna on earth where it can be used in place of conventional power sources. Fig. 24 shows concept of satellite solar power station.

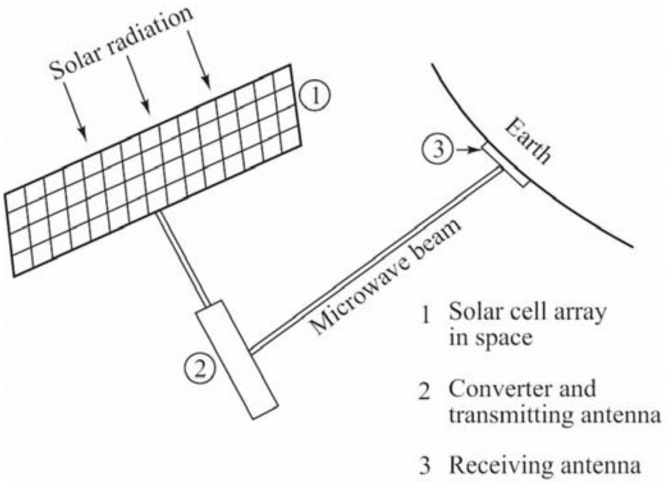

FIG. 24 SATELLITE SOLAR POWER STATION CONCEPT

The advantage of placing the solar collectors in space is the unobstructed view of the sun, unaffected by the day/night cycle, weather, or seasons. However, the costs of construction are very high, and SPSs will not be able to compete with conventional sources unless low launch costs can be achieved or unless a space-based manufacturing industry develops and they can be built in orbit from off-earth materials.

Wind Energy

Wind energy is basically harnessing of wind power to produce electricity. The kinetic energy of the wind is converted to electrical energy. When solar radiation enters the earth's atmosphere, different regions of the atmosphere are heated to different degrees because of earth curvature. This heating is higher at the equator and lowest at the poles. Since air tends to flow from warmer to cooler regions, this causes what we call winds, and it is these airflows that are harnessed in windmills and wind turbines to produce power. Wind power is not a new development as this power, in the form of traditional windmills -for grinding corn, pumping water, sailing ships – have been used for centuries. Now wind power is harnessed to generate electricity in a larger scale with better technology. Fig. 25 shows wind turbine.

FIG. 25 WIND TURBINE

Wind Energy Technology

The basic wind energy conversion device is the wind turbine. Although various designs and configurations exist, these turbines are generally grouped into two types:

Vertical-axis wind turbines, in which the axis of rotation is vertical with respect to the ground (and roughly perpendicular to the wind stream).

Horizontal-axis turbines, in which the axis of rotation is horizontal with respect to the ground (and roughly parallel to the wind stream.)

Followings are the major wind energy technology applications:

1) Water Pumping

The livelihood and well-being of people, animals, and crops depends on a reliable, cost-effective supply of clean water. Mechanical wind water pumping machines have been used to pump water from wells for centuries. The technology of modern mechanical water pumpers is relatively simple, the maintenance requirements are modest, and the replacement parts are not difficult to obtain. The mechanical water pumper is the best option in some circumstances. However, because it must be placed close to the water source, it is often unable to capture the best wind resources. A wind electric pumping system overcomes some of the problems with the simple wind water pumper. This system generates electricity, which, in turn, runs an electric pump. Wind electric pumping systems allow greater siting flexibility, higher efficiency of wind energy conversion, increased water output, increased versatility in use of output power, and decreased maintenance and life-cycle costs.

2) Stand-Alone Systems for Home and Business

In many places, wind power is the least-cost option for providing power to homes and businesses that are remote from an established grid. Researchers estimate that wind produces more power at less cost than diesel generators at any remote site with an average wind speed greater than about 4 meters per second. The applications for electricity in households range from operating small household appliances to refrigeration and freezing, heating, cooling, and lighting. Wind turbine performance depends primarily on rotor diameter and wind speed. The amount of power that a turbine produces depends heavily on the wind speed at the turbine height. System designers must weigh improved performance of the wind turbine at higher tower heights against the increased cost and difficulty of installing higher towers.

3) Systems for Community Centers, Schools, and Health Clinics

A larger system can provide power to a centralized community center, health clinic, or school. A power system for a health center can enable the storage of vaccines and radio communication for emergency calls. A power system for a school can provide electricity for computers and educational television, video, and radio. Community centers often find that, in addition to the benefits of the power, such as lighting and cooling, the "waste energy" can be used to charge batteries or make ice for sale to households. Extending the distribution lines to individual homes and creating a "mini-grid" increases the convenience of the power system to the community. Many Laboratory is involved in exploring a new concept that may significantly lower the cost &/or improve the performance of village systems: the "high-penetration" diesel retrofit system. A substantial amount of diesel fuel could be saved with a control strategy and system architecture that allows shutting down the diesel generator when the wind is sufficient to carry the load, and uses short-term battery storage to reduce diesel start-ups during instantaneous lulls in the wind. The energy requirement and equipment size calculations are similar – on a larger scale – to those for the stand-alone system. The best-designed systems will use as much power as possible directly, instead of storing it in batteries. This reduces initial cost and complexity while delivering the wind's energy in the most efficient way. Using some or all of the turbine's output to pump water, grind grain, or run other loads not dependent on utility-grade electricity reduces the need for batteries for storage of constant-frequency AC power.

4) Industrial Applications

The number of dedicated industrial applications for wind power continues to grow. Small wind power systems are ideal for applications where storing and shipping fuel is uneconomical or impossible.

Wind power is currently being used for the following applications:

- telecommunications
- radar
- pipeline control
- navigational aids
- cathodic protection
- weather stations/seismic monitoring
- air-traffic control

Wind machines in industrial applications typically encounter more extreme weather than home power systems and must be designed to be robust with very minimal maintenance.

Bio-Energy

We have used biomass energy or bioenergy - the energy from organic matter - for thousands of years, ever since people started burning wood to cook food or to keep warm. And today, wood is still our largest biomass energy resource. But many other sources of biomass can now be used, including plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. Even the fumes from landfills can be used as a biomass energy source. The use of biomass energy has the potential to greatly reduce our greenhouse gas emissions. Biomass generates about the same amount of carbon dioxide as fossil fuels, but every time a new plant grows, carbon dioxide is actually removed from the atmosphere. The net emission of carbon dioxide will be zero as long as plants continue to be replenished for biomass energy purposes. These energy crops, such as fast-growing trees and grasses, are called *biomass feedstocks.* The use of biomass feedstocks can also help increase profits for the agricultural industry.

There are three major biomass energy technology applications:

1) Biofuels

Converting biomass into liquid fuels for transportation.

Unlike other renewable energy sources, biomass can be converted directly into liquid fuels - biofuels - for our transportation needs (cars, trucks, buses, airplanes, and trains). The two most common types of biofuels are ethanol and biodiesel. Ethanol is an alcohol, the same found in beer and wine. It is made by fermenting any biomass high in carbohydrates (starches, sugars, or celluloses) through a process similar to brewing beer. Ethanol is mostly used as a fuel additive to cut down a vehicle's carbon monoxide and other smog-causing emissions. But flexible-fuel vehicles, which run on mixtures of gasoline and up to 85% ethanol, are now available. Biodiesel is made by combining alcohol (usually methanol) with vegetable oil, animal fat, or recycled cooking greases. It can be used as an additive to reduce vehicle emissions (typically 20%) or in its pure form as a renewable alternative fuel for diesel engines. Other biofuels include methanol and reformulated gasoline components. Methanol, commonly called wood alcohol, is currently produced from natural gas, but could also be produced from biomass. There are a number of ways to convert biomass to methanol, but the most likely approach is gasification. Gasification involves vaporizing the biomass at high temperatures, then removing impurities from the hot gas and passing it through a catalyst, which converts it into methanol. Most reformulated gasoline components produced from biomass are pollution-reducing fuel additives, such as methyl tertiary butyl ether (MTBE) and ethyl tertiary butyl ether (ETBE).

2) Biopower

Burning biomass directly, or converting it into a gaseous fuel or oil, to generate electricity.

Biopower, or biomass power, is the use of biomass to generate electricity. There are six major types of biopower systems: direct-fired, cofiring, gasification, anaerobic digestion, pyrolysis, and small, modular. Most of the biopower plants in the world use direct-fired systems. They burn bioenergy feedstocks directly to produce steam. This steam is usually captured by a turbine, and a generator then converts it into electricity. In some industries, the steam from the power plant is also used for manufacturing processes or to heat buildings. These are known as combined heat and power facilities. For instance, wood waste is often used to produce both electricity and steam at paper mills. Many coal-fired power plants can use cofiring systems to significantly reduce emissions, especially sulfur dioxide emissions. Cofiring involves using bioenergy feedstocks as a supplementary energy source in high efficiency boilers. Gasification systems use high temperatures and an oxygen-starved environment to convert biomass into a gas (a mixture of hydrogen, carbon monoxide, and methane). The gas fuels what's called a gas turbine, which is very much like a jet engine, only it turns an electric generator instead of propelling a jet. The decay of biomass produces a gas - methane - that can be used as an energy source. In landfills, wells can be drilled to release the methane from the decaying organic matter. Then pipes from each well carry the gas to a central point where it is filtered and cleaned before burning. Methane also can be produced from biomass through a process called anaerobic digestion. Anaerobic digestion involves using bacteria to decompose organic matter in the absence of oxygen. Methane can be used as an energy source in many ways. Most facilities burn it in a boiler to produce steam for electricity generation or for industrial processes. Two new ways include the use of microturbines and fuel cells. Microturbines have outputs of 25 to 500 kilowatts. About the size of a refrigerator, they can be used where there are space limitations for power production. Methane can also be used as the "fuel" in a fuel cell. Fuel cells work much like batteries but never need recharging, producing electricity as long as there's fuel. In addition to gas, liquid fuels can be produced from biomass through a process called pyrolysis. Pyrolysis occurs when biomass is heated in the absence of oxygen. The biomass then turns into a liquid called pyrolysis oil, which can be burned like petroleum to generate electricity. A biopower system that uses pyrolysis oil is being commercialized. Several biopower technologies can be used in small, modular systems. A small, modular system generates electricity at a capacity of 5 megawatts or less. This system is

designed for use at the small town level or even at the consumer level. For example, some farmers use the waste from their livestock to provide their farms with electricity. Not only do these systems provide renewable energy, they also help farmers and ranchers meet environmental regulations. Small, modular systems also have potential as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

3) Bioproducts

Converting biomass into chemicals for making products that typically are made from petroleum.

Whatever products we can make from fossil fuels, we can make using biomass. These bioproducts, or biobased products, are not only made from renewable sources, they also often require less energy to produce than petroleum-based products. Researchers have discovered that the process for making biofuels - releasing the sugars that make up starch and cellulose in plants - also can be used to make antifreeze, plastics, glues, artificial sweeteners, and gel for toothpaste. Other important building blocks for bioproducts include carbon monoxide and hydrogen. When biomass is heated with a small amount of oxygen present, these two gases are produced in abundance. Scientists call this mixture biosynthesis gas. Biosynthesis gas can be used to make plastics and acids, which can be used in making photographic films, textiles, and synthetic fabrics. When biomass is heated in the absence of oxygen, it forms pyrolysis oil. A chemical called phenol can be extracted from pyrolysis oil. Phenol is used to make wood adhesives, molded plastic, and foam insulation.

Hydro Energy

The potential energy of falling water, captured and converted to mechanical energy by waterwheels, powered the start of the industrial revolution. Wherever sufficient head, or change in elevation, could be found, rivers and streams were dammed and mills were built. Water under pressure flows through a turbine causing it to spin. The Turbine is connected to a generator, which produces electricity (Fig. 26).

FIG. 26 HYDRO ENERGY

1) Small Hydro

Small Hydro Power is a reliable, mature and proven technology. It is non-polluting, and does not involve setting up of large dams or problems of deforestation, submergence and rehabilitation. India has an estimated potential of 10,000 MW .

2) Micro Hydel

Hilly regions of India, particularly the Himalayan belts, are endowed with rich hydel resources with tremendous potential. The MNES has launched a promotional scheme for portable micro hydel sets for these areas. These sets are small, compact and light weight. They have almost zero maintenance cost and can provide electricity/power to small cluster of villages. They are ideal substitutes for diesel sets run in those areas at high generation cost. Micro (upto 100kW) mini hydro (101-1000 kW) schemes can provide power for farms, hotels, schools and rural communities, and help create local industry.

Geothermal Energy

Geothermal energy is the heat from the earth. It's clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma. Almost everywhere, the shallow ground or upper 10 feet of the earth's surface maintains a nearly constant temperature between 50° and 60°F (10° and 16°C). Geothermal heat pumps can tap into this resource to heat and cool buildings (Fig 27).

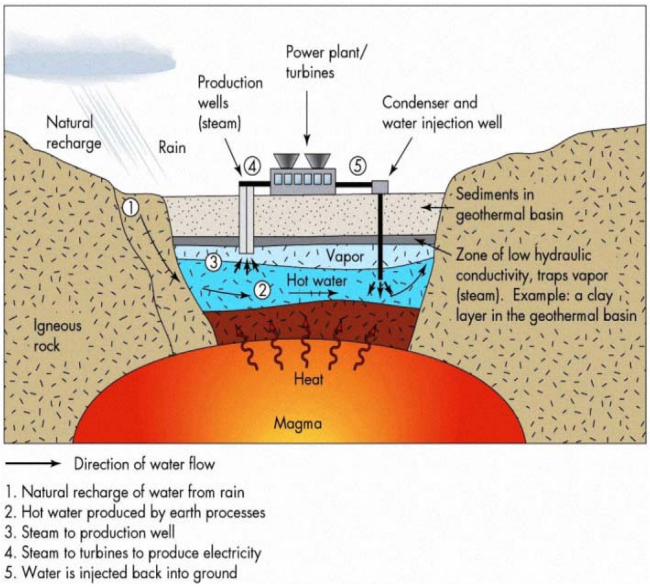

FIG. 27 GEOTHERMAL ENERGY

A geothermal heat pump system consists of a heat pump, an air delivery system (ductwork), and a heat exchanger-a system of pipes buried in the shallow ground near the building. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water. Wells can be drilled into underground reservoirs for the generation of electricity. Some geothermal power plants use the steam from a reservoir to power a turbine/generator, while others use the hot water to boil a working fluid that vaporizes and then turns a turbine. Hot water near the surface of earth can be used directly for heat. Direct-use applications include heating buildings, growing plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes such as pasteurizing milk. Hot dry rock resources occur at depths of 3 to 5 miles everywhere beneath the earth's surface and at lesser depths in certain areas. Access to these resources involves injecting cold water down one well, circulating it through hot fractured rock, and drawing off the heated water from another well. Currently, there are no commercial applications of this technology. Existing technology also does not yet allow recovery of heat directly from magma, the very deep and most powerful resource of geothermal energy. Many technologies have been developed to take advantage of geothermal energy - the heat from the earth. Following are the applications of geothermal energy:

1) *Geothermal Electricity Production*

Generating electricity from the earth's heat.

Most power plants need steam to generate electricity. The steam rotates a turbine that activates a generator, which produces electricity. Many power plants still use fossil fuels to boil water for steam. Geothermal power plants, however, use steam produced from reservoirs of hot water found a couple of miles or more below the earth's surface. There are three types of geothermal power plants: dry steam, flash steam, and binary cycle.

Dry steam power plants draw from underground resources of steam. The steam is piped directly from underground wells to the power plant, where it is directed into a turbine/generator unit.

Flash steam power plants are the most common. They use geothermal reservoirs of water with temperatures greater than 360°F (182°C). This very hot water flows up through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils into steam. The steam is then separated from the water and used to power a turbine/generator. Any leftover water and condensed steam are injected back into the reservoir, making this a sustainable resource.

Binary cycle power plants operate on water at lower temperatures of about 225°-360°F (107°-182°C). These plants use the heat from the hot water to boil a working fluid, usually an organic compound with a low boiling point. The working fluid is vaporized in a heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated. The water and the working fluid are kept separated during the whole process, so there are little or no air emissions.

Small-scale geothermal power plants (under 5 megawatts) have the potential for widespread application in rural areas, possibly even as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

2) *Geothermal Direct Use*

Producing heat directly from hot water within the earth.

When a person takes a hot bath, the heat from the water will usually warm up the entire bathroom. Geothermal reservoirs of hot water, which are found a couple of miles or more beneath the earth's surface, can also be used to provide heat directly. This is called the direct use of geothermal energy. Geothermal direct use dates back thousands of years, when people began using hot springs for bathing, cooking food, and loosening feathers and skin from game. Today, hot springs are still used as spas. But there are now more sophisticated ways of using this geothermal resource. In modern direct-use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well, and a mechanical system - piping, a heat exchanger, and controls - delivers the heat directly for its intended use. A disposal system then either injects the cooled water underground or disposes of it on the surface. Geothermal hot water can be used for many applications that require heat. Its current uses include heating buildings (either individually or whole towns), raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes, such as pasteurizing milk. With some applications, researchers are exploring ways to effectively use the geothermal fluid for generating electricity as well.

3) Geothermal Heat Pumps

Using the shallow ground to heat and cool buildings.

The shallow ground, the upper 10 feet of the earth, maintains a nearly constant temperature between 50° and 60°F (10°-16°C). Like a cave, this ground temperature is warmer than the air above it in the winter and cooler than the air in the summer. Geothermal heat pumps take advantage of this resource to heat and cool buildings. Geothermal heat pump systems consist of basically three parts: the ground heat exchanger, the heat pump unit, and the air delivery system (ductwork). The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to heat water, providing a free source of hot water. Geothermal heat pumps use much less energy than conventional heating systems, since they draw heat from the ground. They are also more efficient when cooling your home. Not only does this save energy and money, it reduces air pollution.

Tidal and Ocean Energy

Tidal electricity generation involves the construction of a barrage across an estuary to block the incoming and outgoing tide. The head of water is then used to drive turbines to generate electricity from the elevated water in the basin as in hydroelectric dams. Barrages can be designed to generate electricity on the ebb side, or flood side, or both. Tidal range may vary over a wide range (4.5-12.4 m) from site to site. A tidal range of at least 7 m is required for economical operation and for sufficient head of water for the turbines. Oceans cover more than 70% of earth’s surface, making them the world’s largest solar collectors. Ocean energy draws on the energy of ocean waves, tides, or on the thermal energy (heat) stored in the ocean. The sun warms the surface water a lot more than the deep ocean water, and this temperature difference stores thermal energy. The ocean contains two types of energy: thermal energy from the sun’s heat, and mechanical energy from the tides and waves.

Ocean thermal energy is used for many applications, including electricity generation. There are three types of electricity conversion systems: closed-cycle, open cycle, and hybrid. Closed cycle systems use the ocean’s warm surface water to vaporize a working fluid, which has a low boiling point, such as ammonia. The vapour expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine / generator. The hybrid systems combine both closed-cycle and open-cycle systems.

Ocean mechanical energy is quite different from ocean thermal energy. Even though the sun affects all ocean activity, tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. A barrage (dam) is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator.

India's Energy Scenario

The potential of various renewable energy technologies in India are estimated by IREDA and are listed in Table 1.

TABLE 1 CUMULATIVE DEPLOYMENT OF VARIOUS RENEWABLE ENERGY SYSTEMS/ DEVICES IN THE COUNTRY AS ON 31 DEC 2012.

Renewable Energy Programme/ Systems	Cumulative Achievements (as on 31 December 2012)
I. Power from Renewables	In MW
A. Grid interactive power	
Wind Power	18420.40
Small Hydro Power	3464.59
Biomass Power	1248.60
Bagasse Cogeneration	2239.63
Waste to Power (Urban and Industrial)	96.08
Solar Power (SPV)	1176.25
Sub total (A)	**26677.10**
B. Off grid/captive power	
Waste to energy	113.60
Biomass (Non-Bagasse) Cogeneration	426.04
Biomass Gasifier (Rural and Industrial)	155.596
Aero-Generators/Hybrid Systems	1.74
SPV Systems (>1 kW)	106.33
Water Mills/Micro Hydel	2121 nos.
Sub total (B)	**803.306**
Total (A+B)	**27480.40**
II. Remote Village Electrification (villages/hamlets)	
III. Other renewable energy systems	
Family Type Biogas Plants (in lakh)	45.86
Solar Water Heating Systems - Collector Area (million sq m)	6.17

Fig. 28, Fig. 29, Fig. 30 and Fig. 31 clearly show projections of India's energy scenario. The Government of India's (GoI) planning commission predicts dramatic demand increases for coal and oil over the next 20 years. Fig. 28 shows projections of India's energy requirements in its Integrated Energy Policy (IEP) report published in August 2006.

Nuclear energy now contributes more than 4,000 MW of power using a largely indigenous technology, but the nuclear industry's development has been hamstrung by India's refusal to sign the Nuclear Non-Proliferation Treaty, cutting the country off from cooperation and assistance in civil nuclear technology.

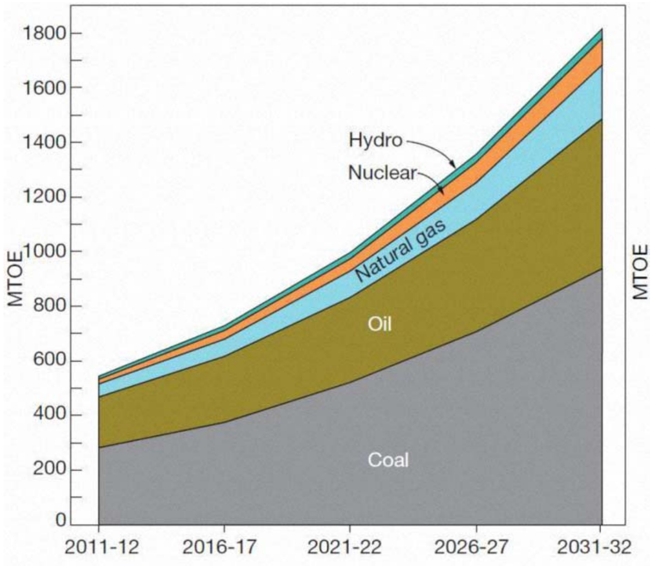

FIG. 28 TOTAL ENERGY REQUIREMENTS

In 2008, India and the Nuclear Suppliers' Group agreed on a waiver to the embargo on trade in nuclear technology. The waiver has removed most of the obstacles, and India now is planning to have 63,000 MW of nuclear generating capacity by 2032. India's long-range plans, however, foresee coal as the sector with the most growth potential, fueled mostly by demand for power generation (Fig 29).

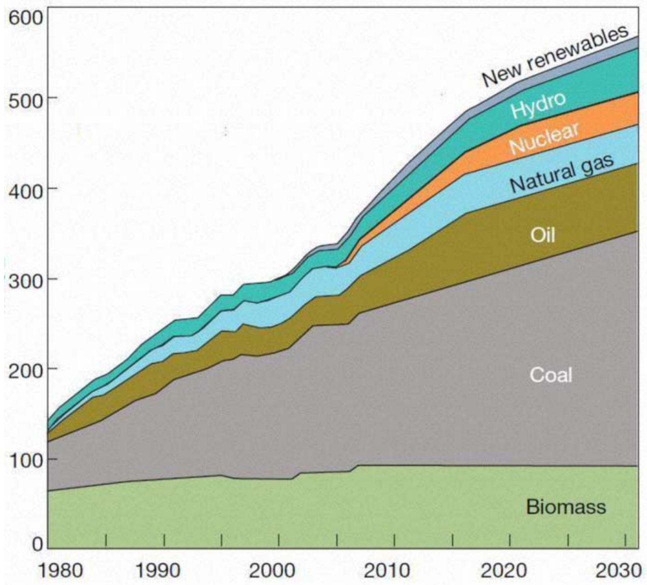

FIG. 29 TOTAL PRIMARY ENERGY BY SOURCES

Pell-mell load growth driven by the fast-expanding economy has left India scrambling to catch up with electricity demand as power outages bedevil the country. The Electric Power Survey 17 forecasts a peak demand growth of 9% for the period up to the end of the XI Plan (2011-12) against actual achievement of 5.3% (Fig 30). In 2009, CRISIL research estimated that

roughly $160 billion would likely be invested in the power sector by 2014. About $100 billion would be in generation, with nearly half of that from private investors.

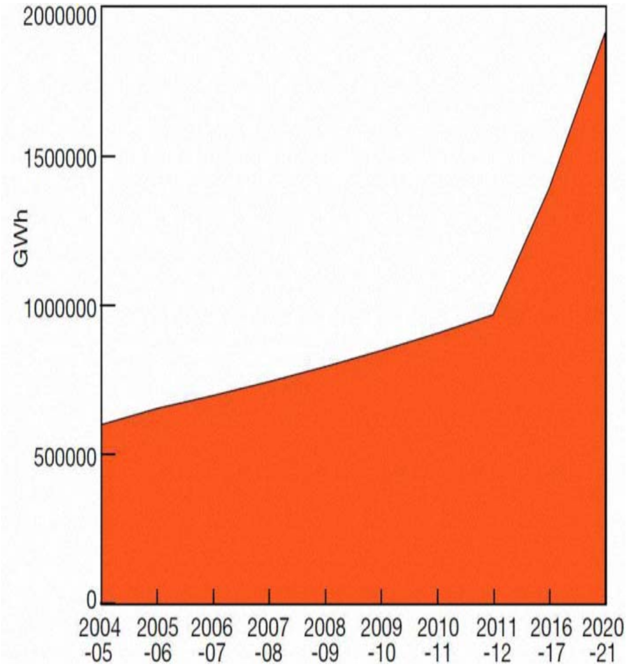

FIG. 30 PROJECTION OF ACTUAL POWER REQUIREMENT

Spikes in power demand from the agricultural sector are forcing state governments to increase load shedding in the summer months. For example, the power deficit in state of Punjab is so severe that it has mandated a one-day-per-week power cut for the steel manufacturing industry, which could be extended to two days if the situation remains unchanged. Plans for increased capacity and power management initiatives are being explored to reduce the cost and increase the reliability of electricity to customers.

A variety of initiatives are in the works to boost additional capacity from public and private players, including UMPPs, MPPs, and group captive generation. Despite these ambitious targets, power demand will likely outstrip supply well into the XII Plan period (Fig 31). In January 2010, KPMG released a report that offers insightful perspectives on the future of the power generation, entitled Power Sector in India: White Paper on Implementation Challenges and Opportunities. With such large-scale development taking place in the power sector and the associated challenges, the importance of comprehensive project management organization is paramount to ensure that projects are completed in a thorough and timely manner.

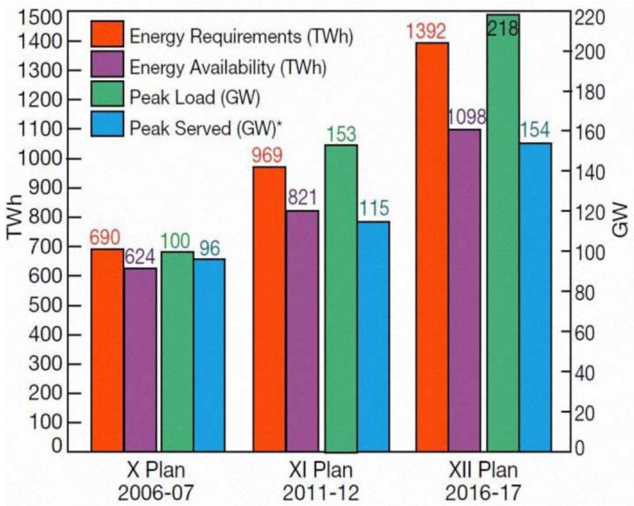

FIG. 31 DEMAND /SUPPLY FORECASTS

Conclusions

In order to minimize the levels of import dependency in the future, it is imperative to focus on increasing the supply of indigenous energy resources. Hence, India should plan to enhance efforts in R&D in the exploration and production of energy resources. There is an urgent need for transition from petroleum-based energy systems to one based on renewable resources to decrease reliance on depleting reserves of fossil fuels and to mitigate climate change. In addition, renewable energy has the potential to create many employment opportunities at all levels, especially in rural areas. So Isolated systems, whose cost depends on load factor are needed to be linked with rural industry. Innovative financing is also a requirement.

Mainstreaming of renewables is very essential. Energy security, economic growth and environment protection are the national energy policy drivers of any country of the world. The need to boost the efforts for further development and promotion of renewable energy sources has been felt world over in light of high prices of crude oil.

A disparaging part of the solution lies in promoting renewable energy technologies as a way to address concerns about energy security, economic growth in the face of rising energy prices, competitiveness, health costs and environmental degradation. The cost-effectiveness of Wind and Small Hydro power energy should also be taken into account.

An emphasis should be given on presenting the real picture of massive renewable energy potential; it

would be possible to attract foreign investments to herald a Green Energy Revolution in India.

Specific action include promoting deployment, innovation and basic research in renewable energy technologies, resolving the barriers to development and commercial deployment of biomass, hydropower, solar and wind technologies, promoting straight (direct) biomass combustion and biomass gasification technologies, promoting the development and manufacture of small wind electric generators, and enhancing the regulatory/tariff regime in order to main stream renewable energy sources in the national power system.

REFERENCES

Basic definitions available at: http://en.wikipedia.org/wiki/Energy.

Coal Statistics from Annual Report 2009-10 available at: http://coal.nic.in/annrep0910.pdf.

Details of history of departments for Renewable Energy: http://www.mnre.gov.in/.

Energy Consumption by Sector in 2007: China, India, Japan, Russia, EU-27, and the United States available at: http://www.earthtrendsdelivered.org/energy_consumption_by_sector_in_2007_china_usa_india_japan_russia_eu-27.

Energy Policy of India available at: http://en.wikipedia.org/wiki/Energy_policy_of_India.

Ghosh, D., Shukla P. R., Garg A., and Ramana V.P. "Renewable energy technologies for the Indian power sector: mitigation potential and operational strategies". Renewable and Sustainable Energy Reviews 6 (2002):481–512.

Golait, N., Moharil, R.M. and Kulkarni P.S. Wind electric power in the world and perspectives of its development in India. Renewable and Sustainable Energy Reviews 13 (2009): 233–247.

GOI. Tenth Five year plan 2002–2007, planning commission, New Delhi. Available at: http://planningcommission.nic.in/aboutus/committee/wrkgrp11/wg11_ renewable.pdf.

Hydro Power scenario available at: http://www.nhpcindia.com/English/Scripts/Hydro_Potential.aspx.

India energy Handbook 2011-Demand Driven, Supply Chained, August 2011.

India Energy profile available at: http://tonto.eia.doe.gov/country/country_energy_data.cfm?fips=IN.

India Energy statistics available at: http://www.eia.doe.gov/cabs/India/Full.html.

Indian Renewable Energy Development Agency Ltd. Booklet on Renewable energy of Ministry of Non-Conventional Energy Sources, Government of India. http://www.mnre.gov.in/booklets/Book11-e.pdf.

Information and Public Awareness. Booklet on Renewable energy of Ministry of Non-Conventional Energy Sources, Government of India. http://www.mnre.gov.in/booklets/Book12-e.pdf.

Kalogirou, S. Solar energy engineering: processes and systems. London: Academic Press publications, 2009.

Lalwani, M. and Singh, M. "Conventional and Renewable Energy Scenario of India: Present and Future". Canadian Journal on Electrical and Electronics Engineering, 1 (2010): 122-140.

Maczulak, A. Renewable Energy: Sources and Methods. NewYork: InfoBase Publishing, 2010.

Maithani, P. C. Renewable energy policy framework of India. New Delhi: Narosa Publication, 2008.

Major achievement in energy and renewable energy available at: http://www.mnre.gov.in/achievements.htm.

Planning Commission, Govt. of India—September 1995 & September 1996 Projections to 2020–2021.

Quaschning, V. Understanding Renewable Energy Systems. London Sterling, VA, UK and USA: Earthscan, 2005.

Singh, J. and Gu, S. "Biomass conversion to energy in India—A critique". Renewable and Sustainable Energy Reviews, 14 (2010) :1367–1378.

Sukhatme, S. P. and Nayak J. P. Solar Energy. 3rd Ed. New Delhi: Tata McGraw Hill, 2011.

Varun and Singal S. K. "Review of augmentation of energy needs using renewable energy sources in India". Renewable and Sustainable Energy Reviews, 11 (2007):1607– 1615.

Zou'bi, M. Al. "Renewable Energy Potential and Characteristics in Jordan". Jordan Journal of Mechanical and Industrial Engineering, 4-1 (2010): 45-48.

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